Geochemistry of wallrock alterations and radioactive mineralization in the vicinity of Hangaliya auriferous shear zone, Eastern Desert, Egypt.

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ABSTRACT

Some radioactive mineralizations are recorded for the first time in the vucinity of the NW-trending auriferous shear zone of Hangaliya gold mine area. Hydrothermal alterations of the younger granites (monzogranite) resulted in the formation of mineralized granite varieties that essentially consist of quartz and sericite. These varieties and the associating quartz veins contain sulphides, gold and radioactive minerals.

On petrographical and geochemical bases, the studied mineralized granites are distinguished into desilicified and silicified varieties. The latter variety is peraluminous whereas the former is metaluminous to peraluminous. Desilicified samples exhibit evidences of Na-metasomatism viz. albitization accompanied by the enrichment of fluorine that also causes the crystallization of fluorite. On the other hand, silicification follows the trend of greisenization during which the increase of SiO_2 is accompanied by realtive enrichment of some trace elements such as Zr, Ba and Rb. During hydrothermal alterations, concentrations of Li (8-21 ppm) and Be (1-5 ppm) remain almost constant whereas abrupt enrichment of both U (up to 2054 ppm) and F (up to 630 ppm) is documented.

Detailed radiometric study revealed that U within the shear zone is sometimes in disequilibrium state as indicated by the remarkable difference of the obtained uranium concentrations by gamma-ray spectrometry and wet chemical analyses. Separated mineral fractions of both mineralized granites and quartz veins show the presence of uraninite (primary uranium mineral). It is belived that the auriferous shear zone of Hangaliya represents a typical example of vein-type uranium mineralization.

INTRODUCTION

Wadi Hangaliya area is one of the most famous occurrences of gold in Egypt. Gold mineralization at the old gold mine of Hangaliya was studied from the mineralogical and genetic points of view by many authors, e.g. Osman (1989) and Khalil and Helba (1998). Recently, Surour et al. (1999) delineated a NW-SE uraniferous–auriferous shear zone at the Hangaliya gold mine area. They (op. cit.) discussed the multiple source of gold and noticed enrichment of uranium (up to 34 ppm) within the shear zone. The present work presents detailed mineralogical and geocheminal study for the radioactive mineralization that associates gold. An emphasis on the genesis of radioactivity will be also discussed in terms of both lithologic and structural controls. Radioactive mineralizations are recorded elsewhere in the Eastern Desert of Egypt, e.g. Gattar (Salman et al., 1990; Shalaby, 1996), El-Missikat (Bakhit, 1978; El-Bayoumi et al., 1999), El-Erediya (El-Tahir, 1985; Mohamed, 1995) and Qash Amir (Assaf et al., 1998). Most of these authors believed in an intimate realtionship between mineralization and hydrothermal alterations.

METHEDOLOGY

Analytical work was carried out at the laboratories of the Nuclear Materials Authority of Egypt. Concentrations of major oxides were determined by wet chemistry according to the method of Shapiro and Brannock (1962) whereas trace elements were measured by the X-ray fluorecency technique (XRF). Determination of U, Th and equivalent U was conducted by the gamma-ray spectrometry. Concentrations of both U and Th of some samples were determined by wet chemistry using the Arsenazo III method. Radioactive and heavy minerals were separated by heavy liquids and isodynamic separator. Identification of minerals under the binocular microscope was then verified by X-ray diffraction (XRD).

FIELD OBSERVATIONS

In comarison with the younger granites, the studied older granitoids of Wadi Hangaliya area are less frequent. The latter only comprise quartz-diorite that crops out as sporadic low-lying masses along Wadi Shait covering an area of about $5Km^2$ (Fig.1) . It is characterized by low topography, jointing and exfoliation weathering. The investigated quartz-diorite is sometimes lineated. Lineation is more pronounced along faults just at the contact with the arc-metavolcanics due to mylonitization.

The younger granites in the area of study (Fig. 1) are represented by two large NW-SE trending plutons, namely Gebel Nugrus and Gebel Magal El-Harami. Gebel Nugrus pluton is about 16 Km long and 8 Km wide, being of moderate to high rugged topography including the conspicuous peak of Gebel Nugrus. This pluton is dissected by a master strike-slip fault striking nearly N-S and dipping 40° due SE. Small-scale normal faults are also recorded trending NW-SE and nearly E-W. These granites intrude into an ophiolitic melange matrix (Fig. 2a) and arc-metavolcanics and send off-shoots into them. The granite is either massive (Fig. 2b) or jointed (Fig. 2c). Strike of the joint surfaces is N60° -70° E with dips amounting 70°-82° due SE. The rocks are heterogeneous in terms of colour (pink & red) and grain size (medium to coarse) ranging in composition from monzo- to syenogranites. It is difficult in the field to define sharp boundaries between the different granitic varieties because they merge into each other without definite contacts. They contain dark oval-shaped xenoliths of metavolcanics, usually 3x5cm (Fig. 2d) showing variable degrees of assimilation. Sometimes, the syenogranite of Gebel Magal El-Harami carries the arc-metavolcanics as roof-pendants (Fig. 2e). Syenogranite at this locality is porphyritic and contains prominent K-feldspar megacrysts.

NW-trending shear zone is observed in the monzogranite of the southern segment of Gebel Nugrus. The granite becomes mylonitized and cataclased within 3-5m wide shear zone (Fig. 2f). Some auriferous quartz veins are common along the shear zone and shafts for the mining of gold were always dug either inclined or parallel to these veins. Surour et al. (1999) studied in detail the microfabrics of this shear zone in the vicinity of the old gold mine of Hangaliya and concluded that conjugate fracture system and formation of mega- and microscopic porphyroclasts in the sheared granites are the most common features of the sense of shearing. They (op. cit.) showed that the source of gold is multiple, being leached from the ophiolitic serpentinites, arc-metavolcanics and sulphide-bearing dolerite dykes. Field observations of the present work agrees El-Feky (2000) that the auriferous shear zone in the vicinity of Hangaliya gold mine shows some remarks of radioactive anomalies (900-1100 cps). In most cases, both the quartz veins and the sheared granites (mostly quartz-sericite rocks) bear some radioactive minerals which is one of the main topics for discussion in the present paper.

PETROGRAPHIC CHARACTERISTICS

The modal composition of Wadi Hangaliya granitic rocks was determined using a point counter. Seventeen thin-sections of fresh samples were selected; four of them represent older granitoids (quartz-diorite) and thirteen represent younger granites (four Nugrus monzogranite, six Nugrus syenogranite & three Magal El-Harami syenogranite). Using the nomenclature of Streckeisen (1976) for the studied granitic rocks (Fig. 3), it is clear that the older granitoids fall in the tonalite field while the younger granites are plotted in the monzo- and syenogranite fields. Soaking of the small low-lying masses of older granitoids (quartz-diorite) by the voluminous mountain-sized younger granites causes some silicification of quartz-diorite. This is responsible for the intruduction of injected quartz (i.e. secondary) which explains the shift of their modal composition towards the field of tonalite.

A) Quartz-diorite:

The rock consists of plagioclase, K-feldspar, quartz and biotite. Main accessory minerals are opaques, titanite, allanite and apatite. The rock is hypidomorphic and exhibits perthitic and porphyritic textures. Imprints of deformation are expressed by mylonitization classyfing it as mylonitized older granitoid. Plagioclase in the studied samples occurs as zoned phenocrysts that show core alteration to sericite (Fig. 4a). Biotite is usually squeezed between altered plagioclase. A smaller generation of plagioclase is also present showing complete alteration to sericite and corrosion by quartz. Allanite is only confined to the biotite-rich portions, both are associated with opaques. Total opaque percentage amounts 3-4%. They are only represented by normal magnetite occurring as long prismatic or stout crystals. It is highly altered to anatase and titanite. The former is sometimes euhedral and shows slight zoning whereas the latter occurs as either perfect rhombs (Fig. 4b) with few ilmenite relics or in the form of continuous reaction rim at the expense of ilmenite (Fig. 4c).

b) Monzo- and syenogranites:

Monzogranite of the southern segment of Nugrus pluton is equigranular and essentially made up of K-feldspars, plagioclase, biotite and minor muscovite. Main accessories are opaques, titanite, zircon and apatite. Chlorite, sericite and kaolinite are secondary minerals. Two generations of plgioclase are observed in which the fine generation is older, being commonly enclosed by perthite. Several types of perthite fabrics are recorded in both microcline and orthoclase crystals, namely rod-, flame- and patchy-types. Plagioclase is often sutured and corroded by perthite and quartz. Some perthite crystals are rimmed by intermediate plagioclase forming rapakivi texture (Fig. 4d). Chloritization of biotite results in the formation of oriented iron oxide crystals (magnetite) exhibiting a mottled structure. Opaques usually form clusters around biotite and asociate apatite and zircon. Zoned allanite associating opaques is also recorded (Fig. 4e).

Syenogranite represents the northern segment of Nugrus pluton and the whole mass of Gebel Magal El-Harami. In this variety, K-feldspars are represented by orthoclase perthite and antiperthite. Both K-feldspars and plagioclase are juxtaposed and corroded by quartz. Most feldspars occur as phenocrysts embedded in a finer groundmass made up of quartz, biotite, opaques and other accessories. Along the crystal boundaries of K-feldspars, some myrmekitic quartz is also observed. Opaque minerals (1-1.5%) in the Nugrus syenogranite are only represented by ilmenite which shows deformational twinning lamellae and extensive replacement by anatase due to low-temperature oxidation. On the other hand, the Nugrus monzogranite is magnetite-bearing, but some scarce skeletal ilmenite is also recorded, together amounting about 3% of the rock mineralogy. Magnetite in this case exhibits heat martitization (Fig. 4f). Total opaque percentage in Magal El-Harami syenogranite ranges from 1 to 3%. They are mostly represented by ilmenite confined to the mafic minerals. Ilmenite is highly altered to anatase and titanite. The rock also contains coarse cubes of goethite, probably after magnetite. It is worth to mention here that both Nugrus and Magal El-Harami monzo- and syenogranites are completely devoid of any sulphides indicating that both sulphides and gold in both the sheared granites and quartz veins are of exclusive late hydrothermal origin.

c) <u>Mineralized or sheared granites:</u>

Petrographically, the sheared granites are mostly represented by quartz-sericite rocks consisting of quartz, sericite and sulphides in addition to minor carbonates and chlorite. Quartz occurs as strained porphyroclasts with extensive corrosion by sericite. These porphyroclasts are either augen-shaped (Fig. 4g) or irregular (Fig. 4h).

GEOCHEMISTRY OF FRESH AND MINERALIZED GRANITES

a) Fresh younger granites:

Table 1 shows the major and trace element composition of the studied older and younger granites. The geochemical signature of the studied granitic rocks can be deduced from the binary relation of Maniar and Piccoli (1989). This relation suggests metaluminous nature of the studied older granitoids whereas the younger granites range in composition from peraluminous to metaluminous (Fig. 5a). In comparison with the common younger granites of Egypt (El-Gaby, 1975), the peraluminous nature of the studied monzo- and syenogranites is slightly shifted towards the metaluminous one which is greatly attributed to some secondary deuteric alterations, e.g. chloritization of biotite (Scheepers, 1995). Such type of alteration gives rise to relatice increase in the content of alumina. In order to test the tectonic setting of the studied granitic rocks, the Y versus Nb binary relation suggested by Pearce et al. (1984) was used. It is clear that the evolution of the older granitoids was confined to a volcanic-arc regime whereas a within-plate setting for all the studied fresh varieties of younger granites is illustrated (Fig. 5b).

Because of the close geochemical coherence between K^+ and $Rb^{+,}$ the K/Rb ratio is considered as a good petrogenetic indicator for the granitic rocks. Figure 5c shows that the studied older and younger granites plot around the average crustal K/Rb line of 250 suggested by Harris et al. (1983). Scattering of the younger granites points within a wide field extending from the mantle line MT (K/RB=1000 defined by Shaw, 1968) to below the average crustal line. Lowering of the K/Rb ratio may elucidate that these rocks are generated from deep sources in the lower crust or the upper mantle by partial melting (Gost, 1965; Hart and Aldrich, 1969). In order to clarify and decipher the problem of depth at which the magma was presumably generated, Rb versus Sr binary relation of Condie (1973) is also here considered. It is clear that the crustal depth of both older and younger granites of the present study never exceeds 30 km (Fig. 5d). The obtained depth is consistent with similar values suggested for the crustal evolution of the Pan-African crust (Knopt and Funda, 1975).

b) Mineralized younger granites:

Many of the known granitic rocks might be altered especially after emplacement and solidification. According to Raguin (1976) and Nockolds et al. (1979), granites are modified by the action of residual fluids and hence these rocks undergo deuteric and hydrothermal alterations. Chemical composition of the studied mineralized granites is given in Table 2.

Field and petrographical investigations of the present work indicate that the studied monzogranite was subjectd to hydrothermal alterations especially along the shear zone at the Hangalia gold mine. Formation of sericite and hydrothermal leaching and addition of quartz are the most pronounced features of alteration (i.e. sericitization and silicification). Leroy (1978) and Cathelineau (1986) mentioned that desilicification process is considered as a phenomenon accompanying the alteration stage in ore deposition and it is frequentlt associated with Na-&K-metasomatism. Cuney et al. (1989) noticed that U-minerals are related to certain granite types such as granites with incipient desilicification (dequartzification), albite episyenite and silicified granite. Silicification is a common alteration feature within the shear zone. Shafts of the Hangaliya gold mine are dug along the shear zone, gold, sulphides and radioactive mineralizations are recorded. Pier (1992) stated that SiO_2 required for silicification is regarded to the hydration of feldspars.

<u>i.Hydrothermal alterations (metasomatism):</u>

In order to elucidate the mineralogical and geochemical changes of the studied monzogranite during hydrothermal alteration, the A-B diagram of Debon and Le Fort (1983) is used (Fig. 6a). Peraluminous to metaluminous nature of the sheared mineralized granites is obtained. It is indicated that the desilicified varieties are metaluminous to peraluminous whereas the silicified varieties are exclusively peraluminous. The different processes of hydrothermal alterations can be envisaged using the normative Qz-Ab-Or ternary relation of Stemprok (1979) and the variation of Na_2O against K_2O. According to the normative Qz-Ab-Or composition (Fig. 6b), the mineralized desilicified granite samples are characterized by Na-metasomatism with a shift towards the albite apex which is consistent with the enrichment of fluorine (vector A) as indicated by Manning (1981). Samples exhibiting high SiO_2 content are shifted towards the quartz apex and also show evidences of greisenization. On the other hand, Na-metasomatism viz. albitization proceeds through the replacement of Na^+ for K^+&Ca^{2+} of the pre-existing feldspars but silicification results in the increase of SiO_2 at the expense of other major elements and accompanied by relative increase of some trace elements such as Zr, Ba and Rb.

Cuney et al. (1989) used the typologic Q-P diagram of Debon and Le Fort (1983) to differentiate between the different types of hydrothermal alteration trends (Fig. 6c). Samples with high negative P-parameter of the studied rocks may correspond to the hydrothermally altered rocks. It is clear from the previous figure that samples showing dequartzification follow the second trend representing albitization contemporaneous with dequartzification. Best representation of this trend is displayed by samples No. 13-13&13-1 in which albitization is very pronounced (Na_2O=4.83&4.66 wt%, respectively). Silicification is well pronounced in sample SZ4B (SiO_2=78.50 wt%). This type of alteration is illustrated by the increment of the Q-parameter. All of these alterations are also documented by the Na%-K% relation (Fig. 6d). This diagram also shows that the argillic alteration also associates silicification as shown by samples No. SZ5B &SZ3. Argillic alteration is particularly well expressed by the increase of A-parameter of the peraluminous index which corrseponds to the decrease of alkalies content in relation to alumina.

ii. Behaviour of major and trace elements within the shear zone:

Geochemical variations are caused by the loss or gain of elements. To understand the geochemical behaviour of elements in the mineralized granites, it is recommended to normalize the pattern of such altered rocks to its corresponding fresh granite (Nugrus monzogranite). After that, the reference granite pattern becomes flat at unity and the relative depletion and enrichment are shown by the deviations on both sides of the reference line (Fig. 7). This figure is constructed based on some geochemical data presented in Table 2.

Mineralized granite samples that are characterized by desilicification and Na-metasomatism exhibit enrichment of Al_2O_3, Fe_2O_3, FeO and CaO which is regarded to the alteration of both biotite and feldspars. Fe_2O_3 is relatively higher than FeO which may suggest prevailing oxidation conditions during alteration. Enrichment of CaO reflects the formation of Ca-bearing non-silicates such as epidote, calcite and fluorite. These samples show depletion in SiO_2, TiO_2, MnO, MgO, K_2O and P_2O_5 (Fig. 7a). Depletion in P_2O_5 might be controlled by the dissolution of monazute and xenotime in the assemblage (Cathelineau, 1987). As to the trace elements, enrichment of Cr, Co, Cu, Pb, Zn, Rb, Sr, Ta, Nb, Hf, Y and Nd is noticed whereas Sn, Ba, Ga, Zr and La are depleted (Fig. 7b). During Na-metasomatism of the sheared granites, Sr is added whereas Ba is removed (Cuney et al., 1989). Enrichment of Cr is attributed to the mobility of the element from the adjacent ultramafic rocks that bear chromite and chromian magnetite. Abrupt increase of Pb is indicated by the formation of galena from the hydrothermal fluid. Na-metasomatism led to the depletion of Ba and enrichment of Sr (Table 2&Fig. 7b). On the other hand, silicified samples are enriched in SiO2, Al2O3 and FeO but depleted in TiO_2, Fe_2O_3, MnO, MgO, CaO, Na_2O, K_2O and P_2O_5 (Fig. 7c). Abundances of trace elements are either higher (Cr, V, Cd, Rb, Ba & Zr) or lower (Ni, Co, Cu, Sr, Ta, Nb & Y) than the fresh monzogranite (Fig. 7d). Depletion of Sr is mainly connected to the decrease of Ca whereas Ba increases in the shear zone which causes the crystallization of barite.

Figure 8a&b shows that the desilicified samples are characterized by lower Ba/Rb and Rb/Sr ratios than the fresh monzogranite in spite of the relative enrichment in Rb. Similar feature is also recognized in some episyenitized younger granites of Egypt (c.f. Moharam, 1997; Mahdy, 1998). On the other hand, the silicified samples show higher Ba/Rb and Rb/Sr ratios than the studied fresh monzogranite. The increase of Rb and Rb/Sr ratio indicates that Rb is enriched during late magmatic stages whereas Ba increases due to silicification.These fetures were also noticed in the silicified granites of of the Eastern Desert along shear zones, e.g. Gattar (Moharam, 1997) and El-Erediya gold mine (Arslan et al., 2000). In this respect, Ekwere (1985) used the Ba/Rb and Rb/Sr ratios as good indicators of mineralizations in anorogenic granitic masses, e.g. Banke and Ririwai younger granites of Nigeria.

Concentrations of F increases from 6-80 ppm in the fresh granite to 460-630 ppm in the mineralized granites (quartz-sericite rocks) of the shear zone at Hangaliya gold mine area which is consistent with the common appearance of fluorite. Concentrations of both Li and be remain almost constant upon alteration. Ranges of Li and Be in the mineralized granites amount 8-21 ppm and 1-5 ppm, respectively (Table 3).

RADIOACTIVITY

a) Distribution of U and Th:

i. Older granitoids (quartz-diorite):

Concentration of chemically analyzed uranium (U_c) in the studied quartz-diorite ranges from 50 to 96 ppm with an average of 73.7 ppm (Table 4). These values greatly exceed the radiometrically determined uranium (U_r) that ranges from 15 to 33 ppm suggesting recent mobilization of the element during weathering and hybridization by the younger granites. On the other hand, chemically analyzed thorium (Th_c) ranges from 4 to 6 ppm. Ra(eU) is positively correlated with uranium. Generally the average of the former is 12.25 ppm. Th/U ratio ranges from 0.47 to 1.00 with 0.73 as an average.

ii. Younger granites:

Radiometrically, the concentration of uranium in the Nugrus monzogranite ranges from 3 to 22 ppm with an average of 15.88 ppm, while Th ranges from 17 to 29 ppm with an average of 22.13 ppm. The range of Th/U is wide (0.77 to 9.00 ppm). Uranium in the Nugrus syenogranite ranges from 3 to 31 ppm with an average of 18.87 ppm, while Th ranges from 9 to 2 ppm with an average of 21.29 ppm. Th/U ratio is also high (0.35-9.67). The porphyritic syenogranite of Gebel Magal El-Harami contains uranium varying from 10 to 34 ppm while Th is in the range of 20-36 ppm. Th/U ratio varies from 0.71 to 2.7 with an average of 1.28. The geometric mean of U of the younger granites of Hanagliya area is more than that of the anorogenic granites of Saudi Arabia, 5.6 ppm (Stuckless et al., 1984) and that of the common granitic rocks, 4.5 ppm (Killen, 1979). The geometric meam of U of Wadi Hangaliya younger granites is also higher than the average of uranium in normal granites (4.75 ppm) as given by Rogers and Adams (1969) and Darnely (1982) based on data from different occurrences allover the world.

Concentration of chemically analyzed uranium (U_c) in the studied younger granites ranges from 13 to 149.8 ppm. The clear difference between the radiometrically measured uranium (U_r=3-34 ppm) and the values obtained from the chemical analyses indicates the role of post-magmatic processes in the enrichment of urnium. On the other hand, chemically analyzed thorium (Th_c) ranges from 10.8 to 14 ppm with an average of 12.15 ppm which is lower than Th determined by the radiometry (average Th_r=21.5 ppm). This suggests the relatively higher geochemical stability of Th than U in Wadi Hangaliya younger granites.

iii. Mineralized granites:

As to the desilicified granites, U_r ranges from 16 to 34 ppm with an average of 22.75 ppm, whereas Th_r amounts 20-24 ppm with an average of 22.5 ppm. Ra(eU) content varies from 0.65 to 1.5 ppm (Table 5). Concentration of U_c varies from 358 to 2054 ppm with an average of 940.33 ppm. The marked difference between U_r and U_c is again a function of late secondary processes during the phase of hydrothermal activity as stated before. On the other hand, the silicified granites show U contents varying from 5 to 21 ppm and Th contents in the range of 15-25 ppm. Table 5 also shows that Th/U ratio is in the range of 0.95-4.80. Ra(eU) contents range from 8.99 to 28 ppm. Contents of U_c are again higher than U_r varying from 113 to 665 ppm with 312 ppm as an average.

To classify granitoids on radioactive basis, Yanting et al. (1982) used some statistical parameters, e.g. average content of uranium (X), standard deviation (S) and coefficient variation (C.V.) based on data of 29 granitic massifs in the Eastern Guandong Province, China. According to the work of Yanting et al. (1982), four essential groups of U dispersion are defined (Table 6). The granitic rocks in group IV are mainly biotite granite or two-mica granite, being considered as the most favourable type for uranium mineralization which is the case of the studied granitic rocks of Hangaliya area.

a) <u>Radioactive equilibrium:</u>

Radioactive equilibrium of the studied non-mineralized and mineralized granitic rocks can be determined by two methods. The first method depends on the calculation of the equilibrium factor (P) which is defined as the ratio of radiometrically determined uranium content (U_r) to the radium content [P-factor=U/Ra(eU)] which was suggested by Hussein (1978). The second method for the study of equilibrium is expressed by the ratio of chemically analyzed uranium (U_c) over radiometrically determined uranium (U_r) or D-factor=U_c/U_r (Hansink, 1976). If both P- and D-factors are higher or lower than one, this means addition or removal of uranium respectively. Removal and addition of uranium are argued to some certain geological processes such as hydrothermal alterations resulting in the disturbance of the equilibrium state. Also groundwater may act on some uranium deposits and causes leaching of uranium from its original place and its re-deposition in other places. Another factor controlling the equilibrium state is the loss of radon gas as one of the uranium daughters. Such loss simply occurs due to the solubility of radon in water and its leakage through pore spaces as well as along faults and shear planes.

P- and D-factors of the studied uraniferous granitic rocks were calculated (Tables 4&5). Also, U and Ra(eU) are plotted vesus each other for possible estimation of the equilibrium state and as an approximate estimate to the degree of agreement between the two values (Fig. 9a&b). It is clear that most values of the P-factors of Wadi Hangaliya samples are more than numerical one or unity referring to possible loss of radon resulting in an U/Ra(eU) averages of 2.93, 2.383 and 3.18 for quartz-diorite, younger granites and desilicified granites, respectively. On the other hand, the silicified granites are slightly in disequilibrium state because the average amounts 0.96 suggesting partial leaching of uranium. The averages of D-factor are 3.6, 4.18, 34.09 and 25.52

for quartz-diorite, fresh younger granites, desilicified and silicified mineralized granites, respectively.

According to Reeves and Brooks (1978), uranium attains equlibrium in about 1.5 M.a. Cathelineau and Holligher (1987) stated that uranium mineralization is affected by different stages of alteration. Stages of leaching, mobility and re-deposition of uranium is controlled by hydrothermal solutions and/or supergene fluids which cause a state of disequilibrium in terms of radioactive decay series of uraniferous rocks. From all the previously presented data, the authors are inclined to consider the uranium mineralization of the auriferous shear zone at the Hangaliya gold mine area as mostly recent. This is argued by the fact that most of the radiometric measurements are lower than their chemical counterparts and the need of the gamma-ray measurements to reach the state of equilibrium. Recently, Dawood (1998) and Osmond et al. (1999) presented ages ranging from 10,000 to 80,000 years for the secondary uranium mineralization of El-Missikat and El-Erediya occurrences in the central Eastern Desert of Egypt.

a) <u>Variation of U versus major oxides and trace elements:</u>

The correlation of uranium versus major oxides and trace elements is also studied. Such relation could be expressed statistically in the form of correlation coefficient which is defined by Rollinson (1993) as the measurement of association strength between two variables measured based on a number of individuals (Table 7a&b). Correlation coefficient between U and Al_2O_3 in the silicified younger granites is positive (Fig. 10a) suggesting that U is enriched during sericitization and chloritiztion. U-mineraliztion in the silicified granite is mainly associated with enrichment of Ni, Cu, Zn and Ba (Fig. 10b). Strong positive correlation between U and some chalcophile elements (Cu and Zn) indicates that U-mineralization is linked to the formation of sulphides. The ascending mineralizing solutions from deep sources at reducing level are characterized by U in the tetravalent state. The enrichment of Ba with U is explained by the crystallization of barite.

In the desilicified granites, U shows positive correlation with Fe_2O_3 which supports the enrichment of uranium during prevailing oxidation conditions (Fig. 10c). Also, U displays strong correlation with Cr, Cu, Pb and Zn (Fig. 10d). Enrichment of Cr versus U reflects the mobility of Cr along the granite-ultramafic contact. Positive correlation between some light REEs (e.g. La, Nd and Sm) in the desilicified granites indicates that these elements are accommodated in the U-bearing minerals.

a) Separated radioactive and heavy minerals:

i. Fresh younger granites:

Radioactive and other accessory minerals in the non-anomalous samples of of the studiedyounger granites are mainly represented by uranophane, zircon, fluorite, allanite, Ti-magnetite, ilmenite and titanite. Uranophane (Fig. 11a) is the only detected secondary U-mineral, being distinguished by its bright lemon to canary yellow. It is found as fissure and veinlets filling (see XRD data, Table 8a). Metamict zircon usually associates biotite and shows pleochroic haloes in it. Fluorite is colourless, yellow or bluish violet (Fig. 11b). Allanite occurs as brown zoned crystals that sometimes grade to the marron colour. Titanite occurs as euhedral to subhedral crystals usually pseudomorphing Ti-bearing opaque minerals (titanomagnetite or ilmenite).

ii. Mineralized rocks of the shear zone:

The contents of radioactive and heavy minerals in the mineralized monzogranites and the associating quartz veins are almost identical. They are represented by uraninite (primary U-mineral), fluorite, galena, pyrite, beudantite, allanite and gold.

Uraninite is recorded by the present authors for the first time at the auriferous shear zone of Hangaliya below the water table in the shafts of the gold mine. The mineral occurs as nearly equant crtstals with steel grey sooty colour (Fig. 11c). It shows sub-metallic lustre and associates galena as inclusions in quartz. Stability of uraninite is much lower than the other U-minerals under the conditions of surface weathering. In fact, the mineral can not be preserved above the water table due to oxidation. XRD data of the studied uraninite are given in Table 8b. Uraninite in the granites and pegmatites of the Eastern Desert of Egypt was also recorded at Gattar (Sayyah and Attawiya, 1990), El-Missikat (Mohamed, 1995) and Qash Amir (Assaf et al., 1998).

Fluorite is often coloured (blue and violet). Appreciable amount of galena is observed. The latter is often altered to cerrucite and stained by Fe-oxides. Pyrite occurs as euhedral to subhedral striated yellow cubes (Fig. 11d) that are partly oxidized to goethite. Arsenopyrite often associates pyrite in the paragenesis. Beudantite (Pb-arsenate) is also recorded for the first time at Hangaliya area. It has a blackish yellow to yellowish brown colour (Fig. 11e). It displays greasy lustre. The mineral is soft, brittle and easily crushed by a needle. XRD data of the investigated beudantite are given in Table 8c. This table also confirms the presence of allanite. Sporadic grains of native gold are found in both quartz veins and mineralized granites (Fig. 11f).

DISCUSSION AND CONCLUSIONS

Radioactive and heavy minerals in the fresh granites of Hangaliya area are represented by secondary U-minerals (uranophane), zircon, allanite, fluorite, magnetite, ilmenite and titanite. On the other hand, the mineralized monzogranite and the associating quartz veins contain primary U-minerals (uraninite), fluorite, galena, pyrite, arsenopyrite, beudantite and gold. Crystallization of beudantite (Pb-arsenate) reflects the important role of arsenic in the mineralization process within the shear zone. Accordingly, the hydrothermally altered monzogranite represents the main target of any future exploration plans for radioactive materials at Wadi Hangaliya area.

Remerkable differences of the obtained uranium concentrations by radiometric and wet chemistry methods (U_r&U_c) indicate the role of post-magmatic processes in the enrichment of uranium. At the contrast, Th is more or less controlled by normal magmatic processes. Enrichment of U is observed in the vicinity of the auriferous shear zone of Hangaliya. Within the shear zone, wallrock alteration resulted in the formation of mineralized granitic rocks, namely desilicified and silicified monzogranites. Both varieties are uraniferous in addition to their remarkable gold budget which led Surour et al. (1999) to notify this zone of mineralization as uraniferous-auriferous shear zone. Chemically analyzed uranium in the desilicified and silicified samples (mostly quartz-sericite rocks) amounts up to 2054 and 665 ppm, respectively. Fresh granites themselves are also radioactive by their own according to the classification of Yanting et al. (1982).

Both P- and D-factors were used in order to test the radioactive equilibrium which indicated that only the silicified variety is in equilibrium. Fresh and desilicified granites show remarks of possible loss of radon or radium, i.e. in disequilibrium state. High U/Th ratio within the mineralized shear zone suggests that U was transported to the site of deposition under oxydizing conditions. Correlation of U with major oxides and trace elements within the shear zone indicates fluctuation of the condition from reduction to oxidation.

The foregoing petrographical, mineralogical and geochemical evidences materialized in the present paper suggest that the studied mineralization represents a vein-type uranium deposit as indicated by the presence of uraninite in many of the investigated quartz veins, in addition to its dispersion in the adjacent altered granites. Similar enrichment of uranium in auriferous shear zones formed by hydrothermal cells were also recorded elsewhere in the world, e.g. at Witwatersand, South Africa (Barnicoat et al., 1997). Mobility of uranium during weathering can not be neglected as it plays an important role in the re-deposition of U-minerals especially the secondary ones. This aspect was also documented for some South African occurences by Scheepers and Rozendaal (1993) and also by Murakami et al. (1997) for some Australian occurrences and recently in Egypt by Dawood (1998) and Osmond et al. (1999). Enrichment of U within the shear zone of Hangaliya increased in the vicinity of mixed circulating meteoric or endogenic (hydrothermal) fluids along the semi-brittle to brittle fractures which goes in harmony with the aspects of deposition (Friedrich et al., 1987; Cuney et al. 1989&1990).

The present work stresses on the environmental impacts of the studied mineralized occurrence in terms of hazards that could happen during mining of gold from such uraniferous zone. Fine dust at the mining sites of gold could cause severe health problems (e.g. lung cancer). Accumulation of radon gas in the shafts and tunnels inside the mine is also a harmful problem which actually needs more detailed environmental studies in the future.

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Figure Captions:

Fig. 1: Geological map of Wadi Hangaliya area

Fig. 2 : Field observations of the younger granites and shear zone:

a. Gebel Nugrus monzogranite intruding low-lying ophiolitic melange
b. General view of Gebel Nugrus massive syenogranite
c. Two sets of joints in the monzogranite
d. Dark oval-shaped metabasalt xenolith in the monzogranite
e. Gebel Magal El-Harami syenogranite (YG) carrying acidic arc-metavolcanics (MV) as foof-pendant
f. A shaft at the Hangaliya gold mine confined to the shear zone in the monzogranite

Fig.3: Modal analysis of Wadi Hangaliya fresh granitic rocks (after Streckeisen, 1976).Fields of tectonic setting are defined by Maniar and Piccoli (1989)

Fig.4: Petrography of the fresh and mineralized granites:

a. Zoned plagioclase showing core replacement by sericite, quartz-diorite, C.N.
b. Perfect titanite rhomb with minute ilmenite relics, quartz-diorite, Reflected Light
c. Ilmenite (Ilm) with continuous titanite reaction rim, quartz-diorite, Reflected Light
d. Rapakivi texture in Nugrus monzogranite, C.N.
e. Zoned allanite in Nugrus monzogranite, P.P.L.
f. Magnetite showing heat martitization, Nugrus monzogranite, Reflected Light
g. Augen-shaped quartz porphyroclast corroded by sericite, mineralized granite, C.N.
h. Irregular quartz porphyroclast corroded by sericite, mineralized granite, C.N.

Fig. 5: Geochemistry of the fresh granitic rocks:

a. Magma-type (Maniar and Piccoli, 1989)
b. Tectonic setting (Pearce et al., 1984)
c. Rb-K% binarry relations. K/Rb lines of 250 & 1000 are taken from Harris et al. (1983) and Shaw (1968), respectively
d. Sr/Rb crustal theckning diagram of Condie (1973)

Symbols as in Fig. 3.

Fig. 6: Geochemistry of the mineralized granites:

a. A-B binary relation of Debon and Le Fort (1983)
b. Qz-Ab-Or ternary diagran of Stemprok (1979). Trends of fluorine enrichment (F) are defined by Manning (1981)
c. Q-P binary relation of Debon and Le Fort (1983)
d. Na%-K% binary relation shwing the different types of alterations

Fig. 7: Histograms showing the enrichment and depletion of elements in the studied mineralized granites with reference to fresh Nugrus monzogranite:

a. & b. Desilicified granites
b. & d. Silicified granites

Fig. 8: Rb-Ba (a) and Sr-Rb (b) relations of the mineralized granites.

Symbols as in Fig. 6.

Fig. 9:P-factor [U/Ra(eU)] of the fresh and mineralized granites

a. Fresh granites
b. Mineralized granites

Fig. 10: Spider diagrams showing the correlation coefficient of uranium against both major oxides and trace elements in the mineralized granites.:

a. & b. Silicified granites
b. & d. desilicified granites

Fig. 11: Separated radioactive and heavy minerals from the fresh & mineralized granites and associating quartz veins from the Hangaliya gold mine:

a. Uranophane (fresh monzogranite)
b. Fluorite (fresh monzogranite)
c. Uraninite (quartz vein)
d. Pyrite (mineralized granite)
e. Beudantite (mineralized granite)
f. Gold (quartz vein & mineralized granite)

<u>Table Captions:</u>

Table 1: Major oxides and trace elements composition of the fresh granitic rocks

Table 2: Major oxides and trace elements composition of the mineralized granite

Table 3: Concentrations of Li, Be & F in the fresh younger granites and the mineralized granites (quartz-sericite rocks) of the shear zone

Table 4: U, Th and equilibrium factors of the fresh granitic rocks

Table 5: U, Th and equilibrium factors of the mineralized granites

Table 6:

Table 7:

Table 8: XRD data of some investigated minerals from Hangaliya shear zone:

a. Uranophane (fresh monzogranite)
b. Uraninite (quartz vein)
c. Beudantite (mineralized granite)